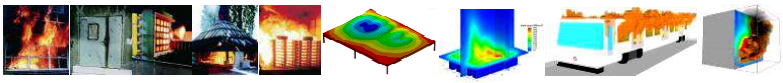


Effect of longitudinal ventilation on the efficiency of water mist in tunnel applications

Mercedes Lago
Tony Lemaire

Content

- Introduction
- Test setup
- Overview of tests
- Results
- Conclusions

Introduction

- **OBJECTIVE OF THE FIRE TEST PROGRAMME:**

  To explore the possibilities and benefits of a water mist suppression **system applied to road tunnels without HVG, as well as the** interaction with other protection measures **like passive fire protection and ventilation systems.**

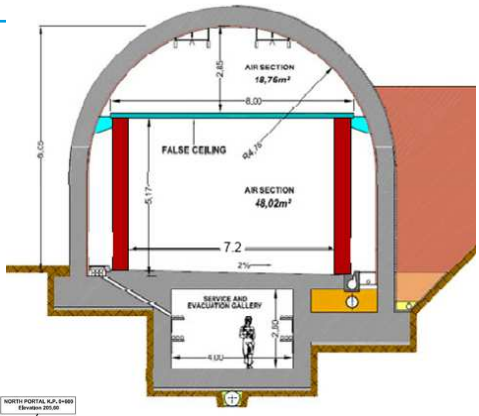
Test Setup

- **22 fire tests have been carried out during April 2012 in the test facility of Tunnel Safety Testing, S.A. (TST), Asturias (Northwest of Spain).**

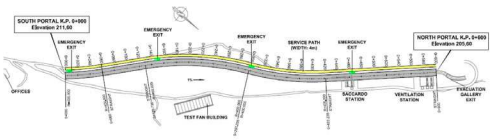
South portal of the tunnel

Test Setup

- **TUNNEL DIMENSIONS:**
  - Lenght: 600 m
  - Rectangular cross-section (7,2 m width x 5,2 m high)



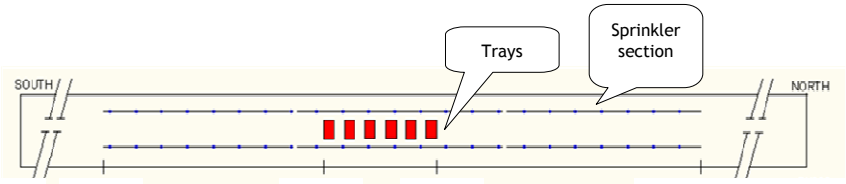
Cross-section



Curvature

Test Setup

- **FIRE SCENARIO:**
  - No heavy goods vehicles are permitted
  - 1 or 6 steel trays (1,2 m x 1,8 m); 200 ltr diesel each
  - HRR estimated (5 MW and 30 MW)



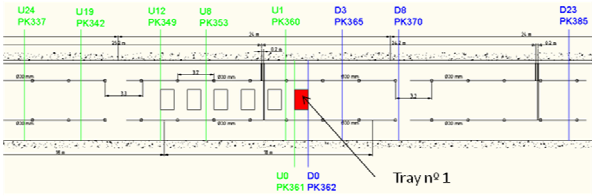
PK0 PK324 PK349 PK362 PK 396 PK 600

LOCATIONS IN TUNNEL

Ventilation direction

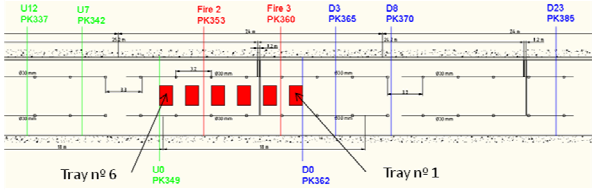
Test Setup

- **FIRE SCENARIO: 1 steel tray - 5 MW**



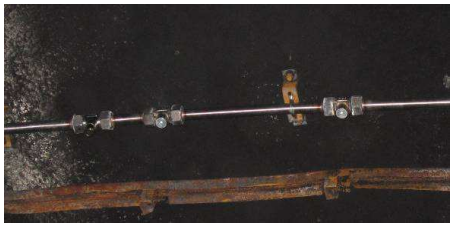
Test Setup

- **FIRE SCENARIO: 6 steel trays - 30 MW**



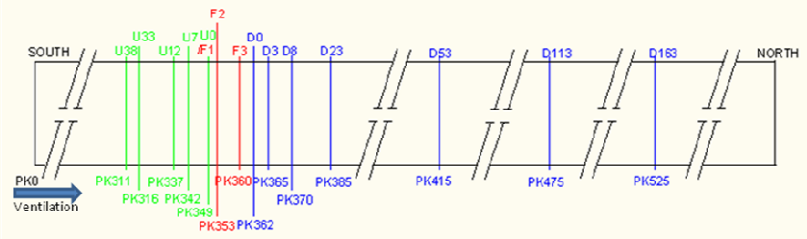
Test Setup

- **THE WATER MIST SYSTEM:**
  - **3 sections of 24 m: 72 m in total (two lines spaced 3.5 m)**
  - **Placed from PK 324 to PK396**
  - **Nozzle spacing: 3.2 m**
  - **K factor: 4.2 lpm/bar0.5**
  - **Pressure: 80 bar**
  - **Activation time: 5 min after ignition**
  - **Discharge duration: 20 min**



Test Setup

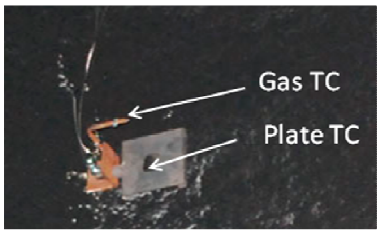
- **INSTRUMENTATION:**
- Measures have been carried out with three different objectives:
  - **life safety**
  - **structural safety**
  - **general fire development**

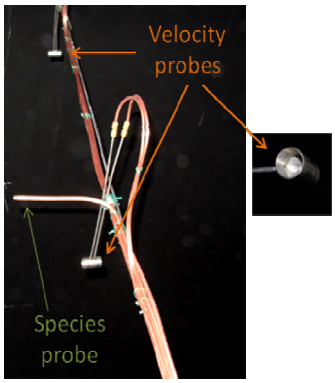


Instrumented cross-sections. 6 trays (30 MW)

Test Setup

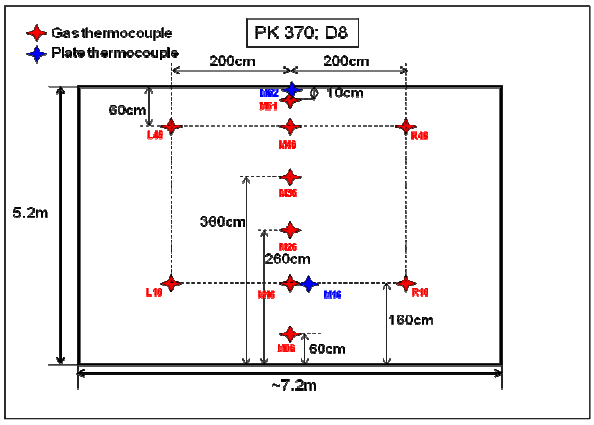
- **INSTRUMENTATION:** temperature, radiation flux and HRR (oxygen depletion method)
  - 10 velocity probes (5 upstream + 5 downstream)
  - 92 gas thermocouples
  - 30 gas thermocouples
  - 2 radiation flux meters
  - 5 species probes (2 O2, 2 CO2, 1 CO)
  - 1 relative humidity sensor





Test Setup

- **INSTRUMENTATION:**



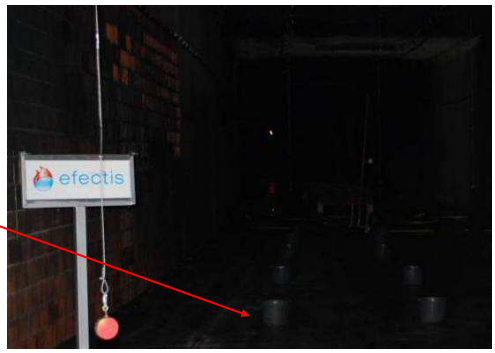
Fully instrumented cross-section

Test Setup

- **INSTRUMENTATION:** flow and pressure of the water mist system
  - 1 flow meter at the entrance of the pump group
  - 2 pressure sensors at the most unfavourable nozzles (furthest from the pump group)

Test Setup

- **INSTRUMENTATION:** effect of ventilation on spray pattern
  - 6 pairs of buckets placed in the centreline of the tunnel and 2 on the left.
  - First pair at PK324, next at 3,8 m; 7,5 m; 11 m, and 14,8 m from the first.
  - Two additional buckets in the centreline at 18,8 m and 47 m



Test Setup

- **INSTRUMENTATION: visibility**
  - **Camera at D78 on the floor looking at light emitting beacons at 10 m (D68), 20 m (D58) and 40 m (D38).**
  - **Beacons placed on a height of 0,60 m and 1,60 m**

Overview of tests

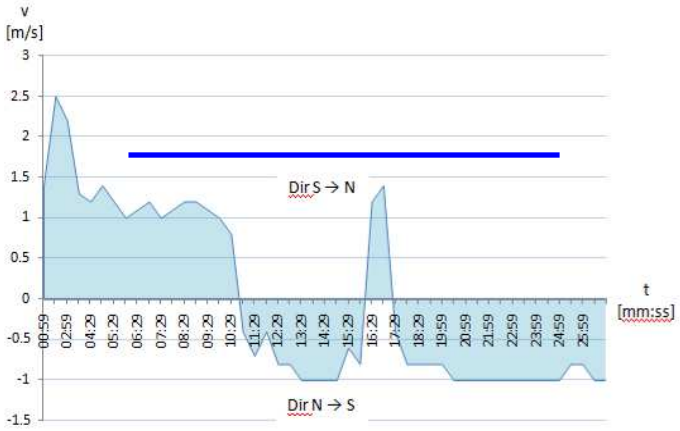
Test	Fuel (RHR peak estimated)	Ventilation (m/s)	Activation Time	Time Discharging
11	Diesel (5MW)	3	5 min after ignition	20 min
12	Diesel (5MW)	5		
13	Diesel (30MW)	3		
14	Diesel (30MW)	5		
15	Diesel I (5MW)	≅ 0		
16	Diesel (30MW)	≅ 0		

1 tray (5 MW)

6 trays (30 MW)

Overview of tests: ventilation Test 16

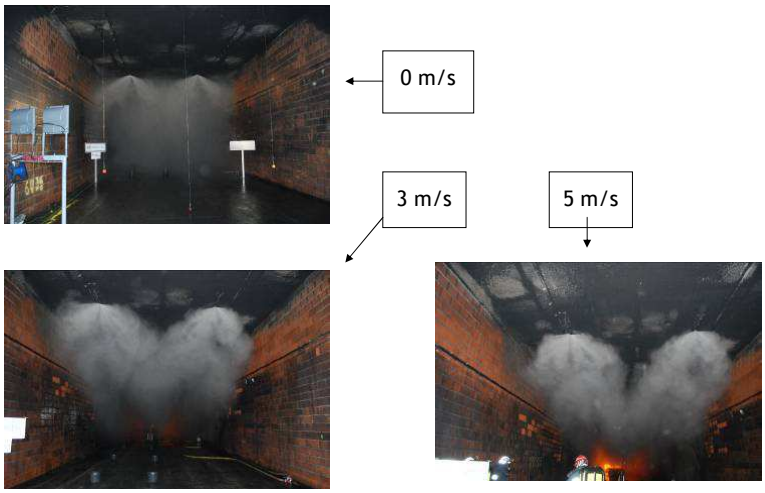
- **Test 16: 6 trays (30MW) ~ 0m/s**



Results

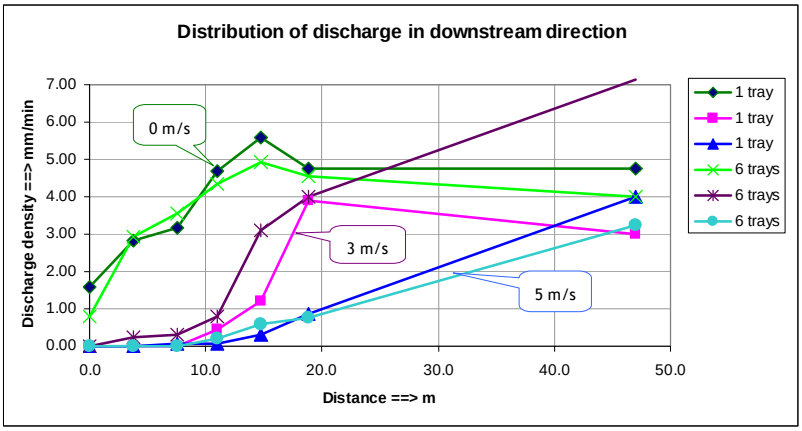
- **Examples of effects of ventilation on:**
  - Spray pattern (local discharge density)
  - Rate of heat release
  - Convection heat flow downstream
  - Tenability conditions downstream
    - Temperature profiles
    - Visibility
    - Toxicity (CO concentrations)
  - Thermal action on ceiling

Effect of ventilation on discharge density



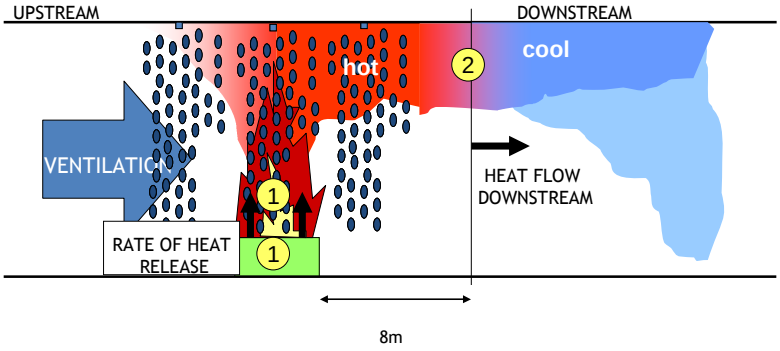
Effect of ventilation on discharge density

- Average discharge density: 4 mm/min
- V = 3 m/s ➔ 4 mm/min on floor at end of first WMS section upstream
- V = 5 m/s ➔ displacement of discharge on floor > 10 m



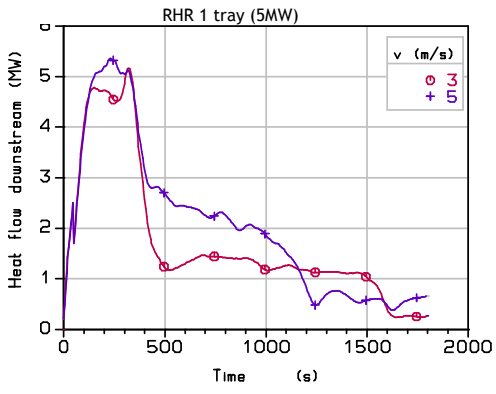
Efficiency of WMS

- **Effects of suppression system on effects of fire**
  - Decrease of combustion = decrease of heat release rate
  - Cooling of combustion products (hot gasses)



Effect of WMS on heat release rate

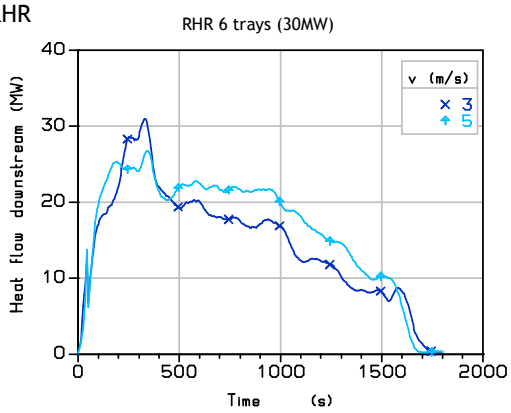
- **1 tray (5 MW):**
  - 3m/s: 25% of free RHR
  - 5m/s: 40% - 50% of free RHR



RHR 6 trays (30MW)

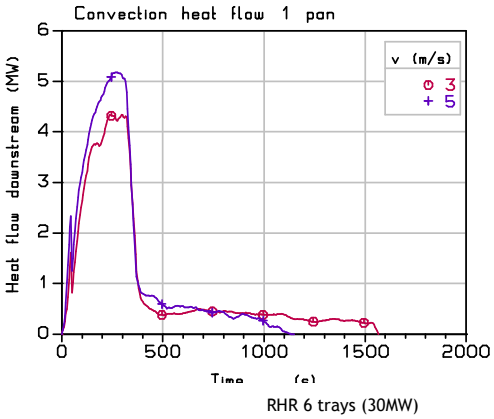
Effect of WMS on heat release rate

- **6 trays (30 MW):**
  - 3m/s: 50% - 66% of free RHR
  - 5m/s: 70% of free RHR



Effect of WMS on convection heat flow

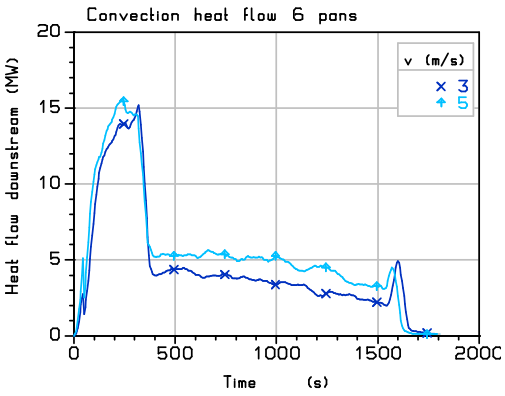
- **1 tray (5 MW)**
  Convection heat flow:
  - 3m/s: 10% of free RHR
  - 5m/s: 10% of free RHR
- ***1 tray (5 MW) RHR:***
  - *3m/s: 25% of free RHR*
  - *5m/s: 40% - 50% of free RHR*



RHR 6 trays (30MW)

Effect of WMS on convection heat flow

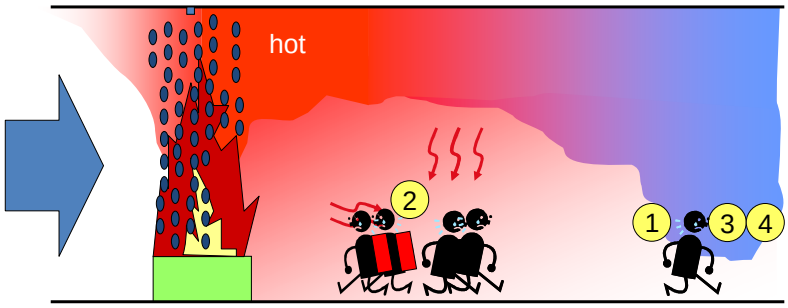
- **6 trays (30 MW):**
  - 3m/s: 13% of free RHR
  - 5m/s: 18% of free RHR
- ***6 trays (30 MW):***
  - *3m/s: 50% - 66% of free RHR*
  - *5m/s: 70% of free RHR*



Downstream conditions for tenability

- **Downstream conditions for tunnel users and fire brigade**
  1. Gas temperature (<50°C; <100°C)
  2. Radiation flux (<2.5kW/m²; 5kW/m²)
  3. Toxicity (>100ppm CO)
  4. Visibility (<10m)

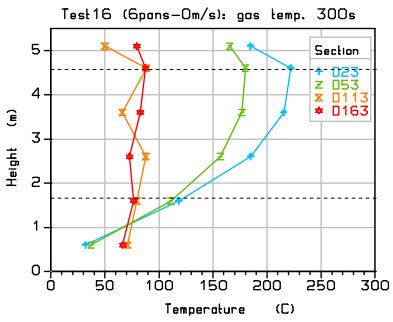
  ] Not applicable for fire brigade with breathing apparatus



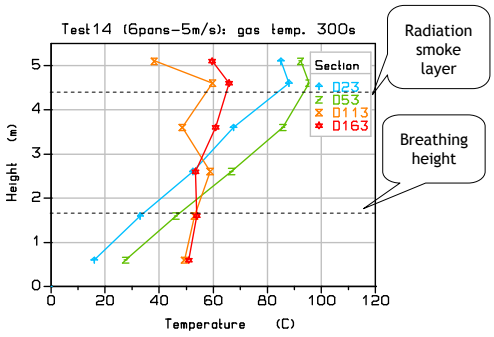
Temperature profiles downstream 6 trays (30MW)

- **Just before activation (t=300s)**
  - V = 0m/s: temperature breathing level: untenable
  - V = 5m/s: temperature breathing level: tenable
- **Higher velocity ➔ higher chance tenable temeprature**

0 m/s



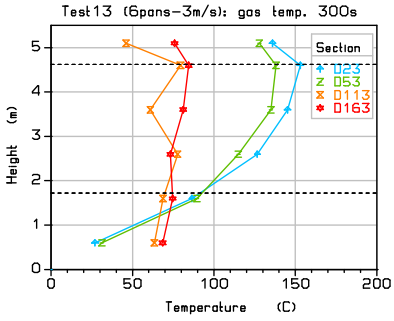
5 m/s



Temperature profiles downstream 6 trays (30MW)

- **Just before activation (t=300s)**
  - V = 3m/s: temperature breathing level: just untenable

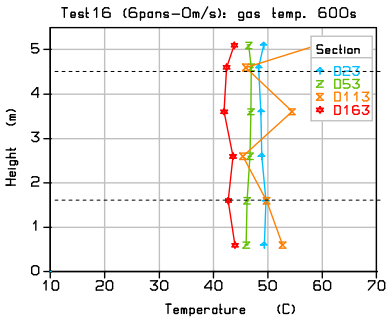
3 m/s



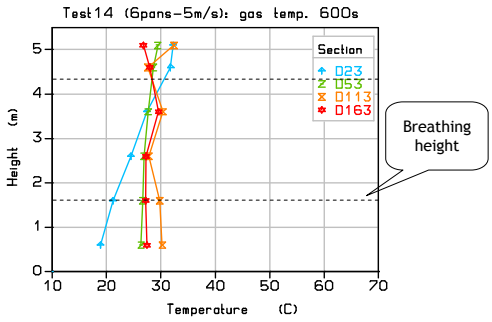
Temperature profiles downstream 6 trays (30MW)

- **5 minutes after activation (t=600s)**
  - V = 0m/s: temperature breathing level tenable
  - V = 5m/s: temperature breathing level: tenable
- **Temperature always tenable after activation**

0 m/s



5 m/s



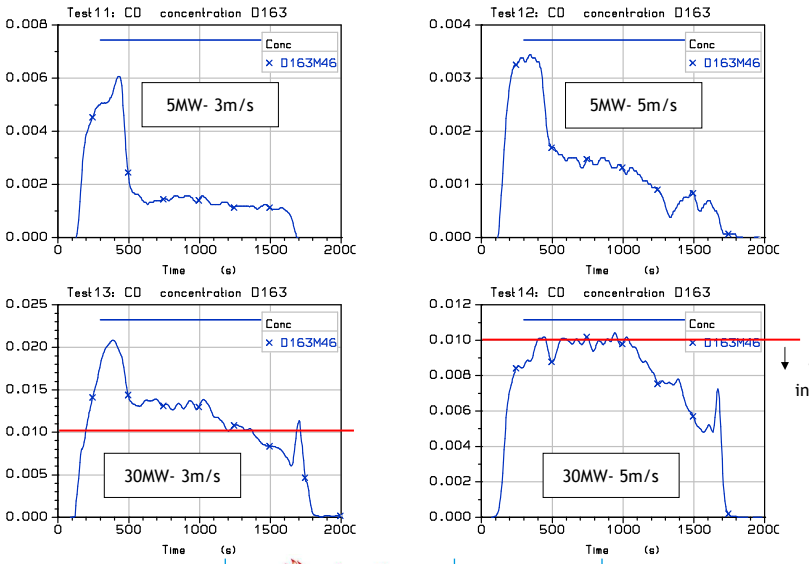
Results: visibility

- **Higher ventilation:**
  - dilution of smoke ➔ visibility increase
  - destratification of smoke ➔ visibility reduction

		NOT VISSIBLE AFTER [mm:ss]					
		1 pan (5MW)			6 pans (30MW)		
Distance [m]	Height [cm]	0 m/s	3 m/s	5 m/s	0 m/s	3 m/s	5 m/s
10	60	05:27	03:22	01:27	02:56	02:33	03:34
10	160	05:22	03:13	01:27	02:56	02:04	03:34
20	60	05:17	03:12	01:15	02:52	02:15	03:34
20	160	05:14	02:52	01:15	02:52	01:34	03:34
40	60	04:11	01:06	00:50	02:18	00:55	01:05
40	160	04:11	01:06	00:50	02:18	00:50	00:57

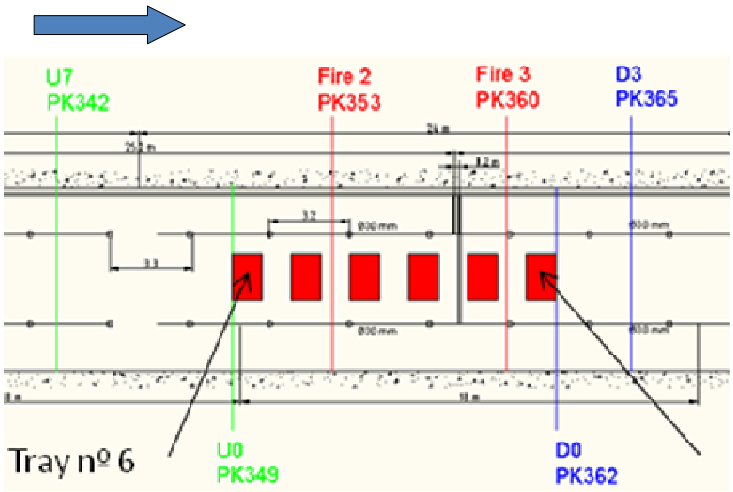
Visibility decrease due to WMS activation

Toxicity: CO concentration

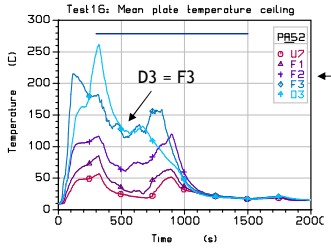


Tenable indefinitely

Thermal action on ceiling: 6 pans (30MW)



Thermal action on ceiling: 6 trays (30MW)

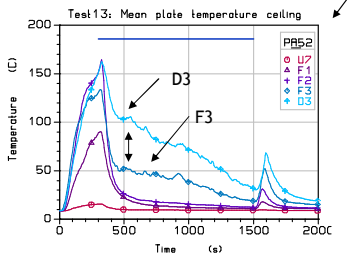


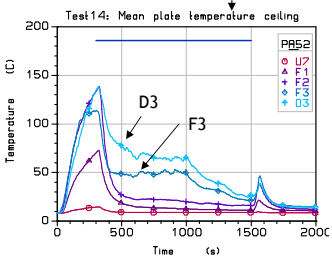
0 m/s

Plate thermocouple = highest possible surface temperature ➔ only indicative for ceiling surface temperature

3 m/s

5 m/s





Thermal action on ceiling: 6 trays (30MW)

- **Small ventilation:**
  - highest temperatures above (F3) and just downstream (D3)
  - temperature drop: 250 C ➔ 140 C within 2 minutes
- **Medium ventilation (3/ms):**
  - highest temperatures downstream (D3) due to inclination of flames
  - temperature drop: 150 C ➔ 100 C within 2 minutes
- **High ventilation (5/ms):**
  - highest temperatures downstream (D3) due to inclination of flames
  - temperature drop: 140 C ➔ 70 C within 2 minutes
- **CONCRETE SPALLING CEILING:**
  - Ventilation decreases risk of concrete spalling

Conclusions for diesel fires up to 30MW

- **The tested WMS is able to control diesel tray fires up to at least 30 MW**
- **Ventilation displaces the spray pattern in downstream direction. This underscores the need for the section upstream of the fire.**
- **Before activation thermal conditions downstream may become untenable. This underscores the need for early detection and activation.**
- **After activation thermal conditions downstream become tenable, but CO may become a problem.**
  - With 5 m/s ventilation CO concentration stays below indefinitely tenable limit (5MW and 30MW), but with 3 m/s not for 30MW.

Conclusions for diesel fires up to 30MW

- **Visibility is reduced below acceptable limits. This is not lethal, but may cause desorentation and longer exposure to thermal and toxicity effects.**
  - With 3 m/s ventilation and 30MW it is not possible to stay in the tunnel indefinitely, because of too high CO level.
  - With 5 m/s ventilation (30MW) it may be possible.
- **Ventilation (3/ms) decreases thermal action on ceiling. This may decrease the risk of concrete spalling. Higher ventilation (5m/s) gives no extra advantage.**

Thank you for your attention!